An Exhibit showing Figures A-C is also attached.

The present claims are rejected based on recapture and prior art. These rejections will be addressed in turn.

A. Recapture

Claims 25-29 stand rejected under 35 U.S.C. §251 as being an improper recapture of broadened claimed subject matter, citing *Hester Industries, Inc. v. Stein, Inc.* 142 F. 3d 1472, 46 USPQ 2d 1641 (Fed. Cir. 1998), *In re Clement*, 131 F. 3d 1448, 45 USPQ 2d 1161 (Fed. Cir. 1997), *Ball Corp. v. United States*, 729 F. 2d 1429, 221 USPQ 289 (Fed. Cir. 1984) and *Pannu v. Storz Instruments Inc.*, 258 F. 3d 1366, 59 USPQ 2d 1597 (Fed. Cir. 2001). However, the office action completely overlooks the 2003 decision of an expanded panel of the Board of Patent Appeals and Interferences in *Ex parte Eggert et al. (*Appeal No. 2001-0790, May 29, 2003. Hereinafter, "*Ex parte Eggert* et al." or "Eggert et al." refers to this decision and not the earlier board decisions also involving Eggert et al.*)*. *Eggert et al.* (1) explains the *Hester*, *Clement*, *Ball* and *Pannu* decisions and (2) is binding precedent on the examining corp so as to control all proceedings within the United States Patent and Trademark Office with regard to the issue of recapture. The office action asserts an

interpretation of the above Federal circuit decisions that is completely contrary to *Eggert et al.*

The central argument in the Office Action is that, if there is a broadening aspect that relates to surrendered subject matter, then *per se* the reissue claim is barred by the recapture rule.

However, this *per se* approach has been expressly condemned in *Eggert et al.* As noted by the Board, a *per se* rule is contrary to express statements in *Clement* and *Pannu*, and the Federal Circuit has never held that germane broadening is a *per se* violation of the recapture doctrine.

Eggert et al. clarified what constitutes surrendered subject matter and what is to be the focus in determining germane broadening and narrowing. The Board stated that the canceled claim constitutes surrendered subject matter, but the subject matter intermediate of the canceled and the issued claim does not. *Ex parte Eggert et al.*, page 5. The Board stated that the focus should be the claim from which the issued claim directly evolved, not the issued claim itself. *Infra*, page 6.

The Board stated that a rigid *per se* rule is not consistent with the remedial nature of the reissue statute and is not supported by the legal precedent of the Federal circuit. *Infra*, page 14. In practical effect, such a *per se* rule would negate

the broadening reissue statute (35 USC 251) with respect to claims amended or argued to gain patentability over the prior art, as well as possibly claims allowed on first action but subject to an examiner's reasons for allowance in the notice of allowability. In other words, under such a rule virtually all broadening reissues would be precluded. If this *per se* rule were to prevail, the reissue statute would be of very little practical value, given that virtually all cases undergo claim amendments, arguments for allowance or examiner's reasons for allowance during prosecution.

The Board cited the following portion of *Clement*:

> Once we determine that an applicant has surrendered the subject matter of the canceled or amended claim, we then determine whether the surrendered subject matter has crept into the reissue claim. Comparing the reissue claim with the canceled claim is one way to do this. If the scope of the reissue claim is the same as or broader than that of the canceled claim, then the patentee is clearly attempting to recapture surrendered subject matter and the reissue claim is, therefore, unallowable. In contrast, a reissue claim narrower in scope escapes the recapture rule entirely. *In re Clement* at 1469, 45 USPQ2d at 1164.

Further, the Board noted that *Clement* and *Pannu* clearly leave open the possibility that reissue claims which have been broadened in an aspect related to surrendered subject matter may avoid the recapture rule if they are materially narrowed in other

respects. *Infra*, page 30. The Board stated that the proper inquiry requires a fact-specific analysis in each case to determine whether the patentee is attempting to recapture surrendered subject matter, in accordance with the basic test of *Clement*. *Infra*, page 31.

On page 6 of its decision, the Board provided a circle diagram to assist in recapture analysis. The Board stated:

> For example, if an outer circle claim contains elements ABC and the inner circle claim contains elements ABCDEF, a reissue applicant cannot recapture a claim directed to elements ABC (outer circle) or a claim entirely outside the outer circle (e.g.,AB, BC, ABC_{BR2}, etc.). However, it is our view that the reissue recapture rule is not invoked for claims directed to elements ABCX, $ABCD_{BR}$, ABCEF, $A_{BR}BCDEF$. In other words, the focus for determining the reach of the reissue recapture rule should be the claim from which the issued claim directly evolved, not the issued claim itself. We believe that this is where we and the members of the dissent disagree. *Infra*, page 6.

The Board recognized that recapture is avoided in some circumstances where the reissue claims are materially narrowed in respects other than those in which the reissue claims are broadened. Further, the Board recognized that recapture does not exist when the reissue claims are materially narrower in *overlooked aspects* of the invention and that the patentee may obtain through reissue a scope of protection to which he is rightfully entitled for such *overlooked aspects*. *Infra*, page 29.

Following the *Clement* test, the Board in *Eggert et al.* applied a three step analysis as follows:

First, the Board compared the reissue claims with the patent claims to determine whether and in what "aspect" the reissue claims are broader than the patent claims.

Secondly, having determined that the reissue claims have been broadened relative to the patent claims, the Board next determined whether those broadenings relate to surrendered subject matter.

Thirdly, the Board compared the rejected reissue claims to the surrendered subject matter to determine in what aspects the reissue claims are broader than the surrendered subject matter and in what aspects the reissue claims are narrower than the surrendered subject matter, with the surrendered subject matter being the claim prior to the amendments resulting in its allowance.

Applying this three step analysis, the applicants initially note that each of claims 25-29 is directed to a "method" and no previous "method" claims, nor manipulative steps, were set forth in any of the claims that were originally presented or amended during prosecution of the parent application which matured into the patent presently undergoing reissue.

Thus, while the present method claims are by definition a broadening aspect, they do not relate to surrendered subject matter because, in the parent application, there was <u>no cancellation of subject matter</u> involving manipulative steps as in presently recited method claims 25-29. The subject matter noted in the office action relates to <u>apparatus limitations</u> which find no identifiable correspondence in the rejected method claims 25-29. Stated another way, the original apparatus claims of the parent application clearly would not be identical to the present method limitations of claims 25-29 in the sense of forming the basis for a double-patenting rejection under 35 U.S.C. 101 under the standard of *In re Vogel*, 422 F.2d. 438, 164 USPQ 619 (CCPA 1970), if contained in different applications. How, then, can any amendment to such original apparatus claims that were not identical to the present method claims suggest a surrender of subject matter of method claims containing manipulative steps allegedly being recaptured in the present claims 25-29?

Applicants respectfully submit that the Office Action, although attempting to determine the differences between the present claims and the claims of the patent, overlooks the significant factor that rejected claims 25-29 are directed to a different statutory class of invention and thus to subject matter <u>not</u> claimed in the original application. Furthermore, the Office

Action lacks consideration of the second step of *Clement* and *Ex parte Eggert*, i.e., that no subject matter was surrendered with respect to this unclaimed subject matter directed to the statutory class of invention known as "process" (method) and that such broadening claims can, thus, be added within the two year time limit of 35 U.S.C. §251.

As noted by the Federal Circuit, the absence of claims of a different statutory class of invention, e.g. process (method) claims, is an error commonly made without deceptive intent, both by applicants and their attorneys and forms the basis for reissue applications. In this regard, applicants respectfully direct the Examiner's attention to the Federal Circuit's Decision *In Schripps Clinic and Research Foundation v. Genetek, Inc.*, 18 USPQ 2d 1001, 1009 (1991), citing *Balcorp v. The United States*, 221 USPQ 289, 296, note 28 "the purpose of the reissue statute is to avoid forfeiture of substantive rights due to error made without intent to deceive" and "the reissue statute is based on fundamental property principals of equity and fairness." When the statutory requirements are met, reissuance of the patent is not discretionary with the Commissioner, it is mandatory (using the word "shall") citing *In re Handle*, 136 USPQ 460, 464 (CCPA 1963). Continuing, the *Schripps* court stated "the law does not require that no competent attorney or alert inventor could have

avoided the error sought to be corrected by reissue." The failure of the attorney to claim the invention sufficiently broadly is "one of the most common sources of defects," citing *In re Wilder*, 222 USPQ 369 (Fed. Cir. 1984), *cert. denied*, 469 US 1209 (1985).

On the undisputed facts here, the inventors each establish that he had claimed less than he had a right to claim, that he had done so in error, and that there was no deceptive intention.

In the *Schripps* case, the reissue added a different statutory basis of claims, i.e., chemical product claims (claims 24-29), which were added to the reissue patent (See, generally, Footnote of *Schripps* at 1003 and the history of the *Schripps* related in *Schripps Clinic and Research Foundation v. Genetek, Inc.*, 3 USPQ 2d. 1481, 1484 (Northern District California 1987)).

In accord, the Office's attention is directed to *C.R. Bard, Inc. v. M3 Systems, Inc.*, 48 USPQ 2d, 1225, 1234 (Fed. Cir. 1998), in which the defendant M3 Systems argued that the original patent was not amenable to correction by reissue because of the addition of claims to an article of manufacture, i.e., needles *per se*, whereas the original invention was directed to a biopsy needle firing device or "gun," mechanically injecting a biopsy needle assembly into body tissue. Here, the Court states, "for a primary purpose of the reissue statute is to enable the addition

of claims to subject matter <u>not claimed</u> in the original patent" (citing *Schripps, supra*) (emphasis added).

The defendant, M3 Systems, argued that since the needles were not claimed originally, they were not "intended" to be claimed and that absence of such intent is not an error correctable by reissue. The Court found that "that too is an incorrect statement of the law." "An inventor's failure to appreciate the scope of invention at the time of the original patent grant, and thus an initial intent to claim the omitted subject matter, is a remedial error" (Citations omitted).

The reissue applicants here had not presented original method claims in the application which matured into the patent undergoing reissue. They have stated through their reissue Declaration that without deceptive intent, they claimed less than they had a right to claim. Clearly, they have complied with the reissue statutes and should be permitted to present and obtain allowance in the reissue application pursuant to 35 U.S.C. §251 to a statutory class of invention not originally contemplated in the original application maturing into the patent undergoing reissue.

The Board Decision in *Eggert et al.*, supports this view. As stated by the Board at pages 3-4 of the Decision, "appellants have never conceded that a claim failing within the scope of the

shaded area of Drawing 1 is unpatentable and, therefore, in our view, such subject matter is not barred by the recapture rule." After discussing the specifics of the invention and claims as set forth in the *Eggert* applications, the Board stated at page 15

> "while we appreciate the dissent's concern for the rights of the public in relying on prosecution history to determine the scope of activities that constituted infringement of the patent claims, we also recognize that (1) the fourth paragraph of 35 U.S.C. §251 clearly places the public on notice that the scope of claims of a patent may be broadened in a reissue application applied for within two years from the grant of patent and (2) the second paragraph of 35 U.S.C. §252 provides safeguards which protect the rights and investments of persons who, prior to the grant of a reissue patent, may, purchase, offer to sell, use in the United States, import into the United States or make substantial preparation for such activities anything patented by the reissued patent and not patented by the original patent. In other words, Congress, while permitting broadening of patent claims by reissue within two years from the grant of a patent to correct errors made by a patentee without deceptive intent, has provided for intervening rights to protect investments made by persons in reliance on the prosecution history of a patent in furtherance of activities which are not covered by the original patent claims but are covered by broadened reissue claims. In this regard, the reissue process stands apart from and in contrast to the application of the doctrine of equivalents, when intervening rights are not provided to protect the public from reliance of prosecution history estoppel in interpreting the scope of the patent claim."

Therefore, applicants respectfully submit that having complied with the reissue statute in stating that they had claimed less than they had a right to claim, without deceptive intent, and that there is no prosecution history estoppel that

any manipulative steps of method claims 25-29 were surrendered, they are entitled to "broaden" the claimed subject matter in the form of the present method claims and the previous narrowing of the original apparatus claims in no way precludes the issuance of method claims 25-29 under the doctrine of reissue recapture.

Moreover, the present method claims constitute <u>overlooked aspects</u> of the invention that were never claimed in the original application given that the original application never contained any method claims. Thus, the Appellants are entitled to obtain the present reissue claims which are directed to overlooked subject matter (method claims) in the original application. These overlooked aspects are sufficient to avoid recapture estoppel.

Further, there is no surrendered subject matter based on the precedential CCPA decision in *In re Wesseler*, 367 F.2d 838, 151 USPQ 339 (CCPA 1966). The CCPA's decision in *Wesseler* is binding legal precedent. *Wesseler* held that there is no surrender based on a prior art rejection, where the canceled claims were subject to both an indefiniteness rejection and a prior art rejection and the record contains nothing to indicate cancellation, amendment or argument to overcome the prior art rejection. Under *Wesseler,* if there is both a 35 USC 112 rejection and a prior art rejection and the record contains nothing to indicate cancellation,

amendment or argument to overcome the prior art rejection, there is no surrender based on a prior art rejection. *In re Clement* reiterates that in reissue recapture, surrender requires cancellation, amendment or argument for the purpose of overcoming a prior art rejection.

The facts underlying the present application are virtually identical in pertinent point to those described by the court in *Wesseler*. Prior to the cancellation of claims in the original patent application for both *Wesseler* and the present case, all claims stood rejected as being vague and indefinite. Also, in *Wesseler*, claims 11, 12, 20, and 21 of the patent application were rejected as unpatentable over a patent to Simmonds, and in the present case, claims 1 and 6 were rejected over prior art. In *Wesseler* and the present case, the PTO alleged improper recapture. Also, in both *Wesseler* and the present case, the PTO alleged, either expressly or impliedly, that the Appllicnats had acquiesced to the rejection made by the examiner in the parent application and thus surrendered the subject matter of the cancelled claims.

Applying *Wesseler* to the present case, there was no surrender invoking the recapture rule because the prosecution history and claim amendments and cancellations fail to support

any inference that original claims 1 and 6 were canceled to overcome a prior art rejection.

The CCPA stated in *Wesseler* that:

> [i]nsofar as the act of cancelling claims is concerned the record does not show whether this was an admission that those claims were unpatentable over the prior art or whether they were cancelled and the amended claims were submitted to cure the 'vague and indefinite' rejection. *Id.*, at 345, 346.

Similarly, the record of the present application provides no indication that the cancellation of claims 1 and 6 was due to the prior art rejection or due to the "vague and indefinite" rejection. Given that the CCPA's decision in *Wesseler* is binding legal precedent for the present situation, the law applied to the Wesseler situation should be similarly applied to the present situation.

Similarly to *Wesseler*, *In re Petrow*, 159 USPQ 485 (CCPA 1968), stated that where the deliberate cancellation of a claim does not amount to an admission that the reissue claims were not patentable at the time the original claims were canceled, there is no surrender and no recapture estoppel. The court stated:

> There are not sufficient facts in the record to base a holding that the cancellation of claim 4 was in any sense an admission, the applicant amended the claims to put claims in proper form under a 112 product by process claim. *Petrow* at 450-451.

Thus, *Wesseler* and *Petrow* stand for the proposition that the recapture rule does not apply absent evidence that applicant's amendment was an admission that the scope of that claim was not in fact patentable over the prior art.

Here, the Office Action does not even assert that the cancellation of claims 1 and 6 was to overcome the prior art.

Here, similarly to *Wesseler*, the cancellation of claims 1 and 6 and the amendments to the allowable claims were done in order to present the claims in a form to allow the invention to be understood, in view of the indefiniteness rejection.

Thus, under the principles of *Wesseler* and *Petrow*, there was no surrender invoking the recapture rule in the present case, because the prosecution history and claim amendments and cancellations fail to support any inference that original claims 1 and 6 were canceled to overcome a prior art rejection.

For the foregoing reasons, withdrawal of the rejection of claims 25-29 under 35 U.S.C. §251 as allegedly being an improper recapture of broadened subject matter is respectfully requested.

B. <u>Prior Art Rejection</u>

Claims 25, 27 and 29 stand rejected under 35 USC 102(e) as anticipated by USPN 5,097,464 to Nishiuchi et al. This rejection is respectfully traversed.

The Office Action proposes that Nishiuchi (US5,097,464) discloses an optical system having at least one of focal distances in Figs. 2a to 2c and Figs. 5a to 5b. However, it is not correct that the optical system in those figures has different focal distances.

Fig. 1 of Nishiuchi shows a converging optical system including an objective lens 8 and a transparent plate 9. The focal distance of the converging optical system is always the same. The reason and the mechanism are explained below.

At first, the Applicants note that the second line on page 5 of the office action cites the converging optical system 9, 11, 17 and 7'' of Nishiuchi. However, plate actuator 11 and voice coil 17 are mechanical parts and they do not directly affect the optical beam. The $\lambda/4$ plate 7 is combined with polarized beam splitter 6 in order to guide the optical beam from the optical disk to photo detectors 14 and 15 but not to laser diode 3. The parts 6 and 7 are placed at the middle of the collimated beam and they do not affect the focal distance, either. Accordingly, the parts relating to the converging optical system are objective lens 8 and transparent plate 8.

The differences between the present claimed invention and Nishiuchi are apparent from the following points.

(1) First Point

Assume the focal distance of objective lens 8 is fa, the focal distance of transparent plate 9 is fb, the focal distance of the converging optical system consisting of the parts 8 and 9 is fab, and the distance between the objective lens 8 and the transparent plate 9 is d. Then,

$$fab = fa \cdot fb/(fa + fb - d) \quad \text{(equation (2.45))}$$

This relation is well known as described on page 45 of *Modern Optical Engineering*, Second edition, published by McGraw-Hill, Inc., 1990. In this reference, focal length is used instead of focal distance.

As described on lines 4 to 9, column 4 of Nishiuchi, the transparent plate 9 is a parallel plane and fb becomes infinitely great (∞). See equation (2.40a) on page 40 of *Modern Optical Engineering, supra*. It is the case that R1 = R2 in equation (2.40a) and f becomes ∞. Accordingly, ∞ is substituted for fb in the equation (2.45), to yield:

$$fab = fa \cdot \infty/\infty = fa$$

Accordingly, the Nishiuchi converging optical system always has a fixed focal distance regardless of the presence of transparent plate 9 or the thickness of transparent plate 9.

(2) Second Point

As mentioned above, Nishiuchi shows a composite optical system consisting of a lens 8 and a transparent plate 9.

With respect to the focal distance, please note the attached Exhibit showing Figure A illustrating a lens. When a collateral light beam parallel with an optical axis of the lens enters the lens from the left side, the beam refracts at the lens front surface and the lens back surface and converges at focal point O. The broken line along which the incident beam is extended crosses the other broken line along which the converging light is extended at point C. A line is drawn from point C to be perpendicular to the optical axis and the crossing point of the drawn line and the optical axis is P. θ represents the angle COP, and CP represents the distance between points P and C. The focal distance fo of the lens is expressed by

$$Fo = OP = CP/\tan \qquad \text{(equation 1)}$$

See attached Figure B of the Exhibit. It is the case that a lens and a transparent plate are used. The light exiting from the

lens refracts when entering the plate and exiting from the plate and converges to the focal point O'. The broken line which the incident beam is extended crosses the other broken line which the converging light is extended at point C'. A line is drawn from point C' to be perpendicular to the optical axis and the crossing point of the drawn line and the optical axis is P'. The focal distance f1 of the optical system including the lens and the plate is O'P'.

Such definition is well-known and shown in Figure 2-17 on page 45 of *Modern Optical Engineering, supra*.

The transparent plate of Nishiuchi is a parallel plane and the incident angle and the emergent angle are the same according to the well-known Snell's law of refraction. The angle C'OP' = θ.

$$f1 = O'P' = C'P'/\tan\theta \qquad \text{(equation 2)}$$

The light entering from the left side into the lens is parallel with the optical axis.

$$CP = C'P' \qquad \text{(equation 3)}$$

According to equations 1 , 2 and 3,

$$fo = f1$$

Accordingly, Nishiuchi shows to <u>move the focal point</u> by inserting the transparent plate or by changing the thickness of the transparent plate. But Nishiuchi does not <u>change the focal distance</u>.

Attention is directed to Figs 4A and 4B of the present application. Fig. 4A corresponds to Figure A and Fig. 4B corresponds to Figure C of the attached Exhibit. In Figure C, the lens is different from that of Figure A. θ'' is larger than θ. The focal distance in Figure A is different from that in Figure C.

(3) Conclusion

Although both Nishiuchi and the present claimed invention show a technique for adaption to different disk thicknesses, the present claimed invention is different from Nishiuchi in the optical approach and structure for making such adaptation. Generally, speaking, the present claimed invention changes the focal distance whereas Nishiuchi changes the focal point. Accordingly, it is submitted that Nishiuchi fails to anticipate the present claimed subject matter.

It is submitted that this application is now in condition for allowance, and a notice to that effect is respectfully requested.

If any issue remain which may best be resolved through a telephone communication, the examiner is requested to telephone the undersigned at the local Washington, D.C. telephone number listed below.

Respectfully submitted,

Date: April 25, 2005

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MODERN OPTICAL ENGINEERING

The Design of Optical Systems

SECOND EDITION

Modern Optical Engineering

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Second Edition

McGraw Hill

Boston, Massachusetts Burr Ridge, Illinois
Dubuque, Iowa Madison, Wisconsin New York, New York
San Francisco, California St. Louis, Missouri

Library of Congress Cataloging-in-Publication Data

Smith, Warren J.
Modern optical engineering : the design of optical systems / Warren J. Smith.—2nd ed.
p. cm.
Includes index.
ISBN 0-07-059174-1
1. Optical instruments—Design and construction. I. Title.
TS513.S55 1990 90–36726
621.36—dc20 CIP

McGraw-Hill

A Division of The McGraw-Hill Companies

8 9 10 11 12 13 14 BKMBKM 9 9 8

ISBN 0-07-059174-1

The sponsoring editor for this book was Daniel A. Gonneau, the editing supervisor was Alfred Bernardi, the designer was Naomi Auerbach, and the production supervisor was Thomas G. Kowalczyk. It was set in Century Schoolbook by McGraw-Hill's Professional and Reference Division composition unit.

$$u_1 = \frac{-(y_1 - h)}{l_1} = \frac{-(0 - 20)}{-300} = -0.0666$$

The calculation of this ray is indicated in the sixth and seventh rows of Fig. 2.10 and yields $y_3 = -0.52888\ldots$ and $n'_3 u'_3 = -0.067555$.

The height of the image, h' in Fig. 2.9, can be seen to equal the sum of the ray height at surface #3 plus the amount the ray climbs or drops in traveling to the image plane.

$$h' = y_3 + l'_3 \frac{N'_3 u'_3}{N'_3} = -0.52888 + (199.6846) \frac{(-0.067555)}{1.0}$$
$$= -14.0187$$

Notice that the expression used to compute h' is analogous to Eq. 2.32; if we regard the image plane as surface #4 and the image distance l'_3 as the spacing between surfaces #3 and #4, Eq. 2.32 can be used to calculate y_4, which is h'.

Similarly, Eq. 2.32 can be used to determine the initial slope angle u_1 by regarding the object plane as surface zero and rearranging the equation to solve for $u'_0 = u_1$ as shown below:

$$y_1 = y_0 + t_0 \frac{N'_0 u'_0}{N'_0}$$

$$u'_0 = u_1 = \frac{y_1 - y_0}{t_0} = \frac{h - y_1}{l_1}$$

2.7 Focal Points and Principal Points of a Single Lens Element

In general, the focal lengths of an optical system can easily be calculated by tracing a ray parallel to the optical axis (i.e., with an initial slope angle u equal to zero) completely through the optical system. Then the effective focal length (efl) is minus the ray height at the first surface divided by the ray slope angle u' after the ray emerges from the last surface. Similarly, the back focal length (bfl) is minus the ray height at the last surface divided by u'. Using the customary convention that the data of the last surface of the system are identified by the subscript k, we can write

$$\text{efl} = \frac{-y_1}{u'_k} \qquad (2.34)$$

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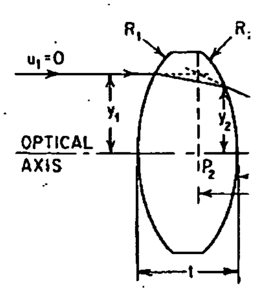
$y_2 = y_1 + \frac{tN'_1}{N}$



$$\text{bfl} = \frac{-y_k}{u'_k} \tag{2.35}$$

The cardinal points of a single lens element can be readily determined by use of the raytracing formulas given in the preceding section. The focal point is the point where the rays from an infinitely distant axial object cross the optical axis at a common focus. This point can be located by tracing a ray with an initial slope (u_1) of zero through the lens and determining the axial intercept.

Figure 2.11 shows the path of such a ray through a lens element. The principal plane (p_2) is located by the intersection of the extensions of the incident and emergent rays. The effective focal length (efl) or focal length (usually symbolized by f), is the distance from p_2 to f_2 and, for the paraxial region, is given by

$$\text{efl} = f = \frac{-y_1}{u'_2}$$

The back focal length (bfl) can be found from

$$\text{bfl} = \frac{-y_2}{u'_2}$$

Owing to the frequency with which these quantities are used, it is worthwhile to work up a single equation for each of them. If the lens has an index of refraction N and is surrounded by air of index 1.0, then $N_1 = N'_2 = 1.0$ and $N'_1 = N_2 = N$. The surface radii are R_1 and R_2, and the surfase curvatures are c_1 and c_2. The thickness is t. At the first surface, using Eq. 2.31a,

$$N'_1u'_1 = N_1u_1 - (N'_1 - N_1)y_1c_1 = 0 - (N - 1)y_1c_1$$

The height at the second surface is found from Eq. 2.32:

$$y_2 = y_1 + \frac{tN'_1u'_1}{N'_1} = y_1 - \frac{t(N-1)y_1c_1}{N} = y_1\left[1 - \frac{(N-1)}{N}tc_1\right]$$

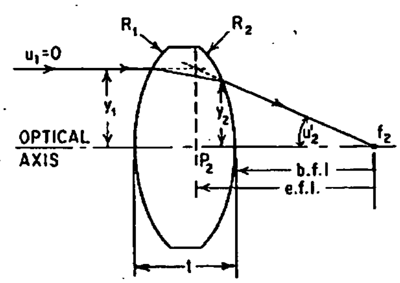


Figure 2.11 A ray parallel to the axis is traced through an element to determine the effective focal length and back focal length.

And the final slope is found by Eq. 2.31a:

$$N'_2u'_2 = N'_1u'_1 - y_2(N'_2 - N_2)c_2$$

$$= -(N-1)y_1c_1 - y_1\left[1 - \frac{(N-1)}{N}tc_1\right](1-N)c_2$$

$$(1.0)u'_2 = u'_2 = -y_1(N-1)\left[c_1 - c_2 + tc_1c_2\frac{(N-1)}{N}\right]$$

Thus the power ϕ (or reciprocal focal length) of the element is expressed as

$$\phi = \frac{1}{f} = \frac{-u'_2}{y_1} = (N-1)\left[c_1 - c_2 + tc_1c_2\frac{(N-1)}{N}\right] \qquad (2.36)$$

or, if we substitute $c = 1/R$,

$$\phi = \frac{1}{f} = (N-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{t(N-1)}{R_1R_2N}\right] \qquad (2.36a)$$

The back focal length can be found by dividing y_2 by u'_2 to get

$$\text{bfl} = \frac{-y_2}{u'_2} = f - \frac{ft(N-1)}{NR_1} \qquad (2.37)$$

The distance from the second surface to the second principal point is just the difference between the back focal length and the effective focal length (see Fig. 2.11); this is obviously the second term of Eq. 2.37.

The above procedure has located the second principal point and second focal point of the lens. The "first" points are found simply by substituting R_1 for R_2 and vice versa.

The focal points and principal points for several shapes of elements are diagramed in Fig. 2.12. Notice that the principal points of an equiconvex or equiconcave element are approximately evenly spaced within the element. In the plano forms, one principal point is at the curved surface, the other is about one-third of the way into the lens. In the meniscus forms shown, one of the principal points is completely outside the lens; in extreme meniscus shapes, both the principal points lie outside the lens and their order may be reversed from that shown. Note that the focal points of the negative elements are in reversed order compared to a positive element.

If the lens element is not immersed in air, we can derive a similar expression for it. Assuming that the object medium has an index of N_1, the lens index is N_2, and the image medium has an index of N_3,

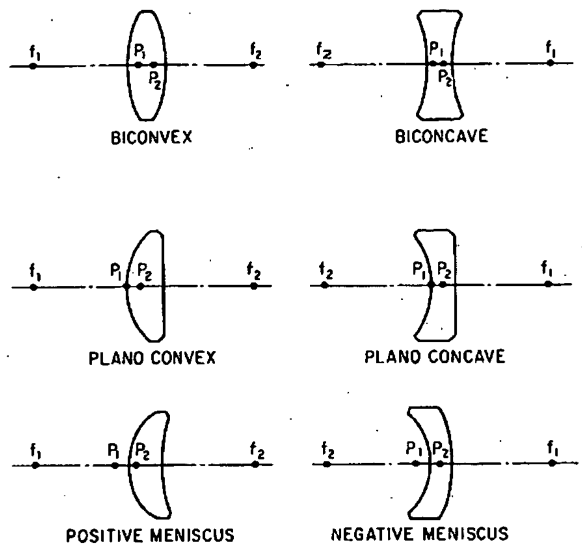


Figure 2.12 The location of the focal points and principal points for several shapes of converging and diverging elements.

then the two effective focal lengths and the back focal length can be calculated from

$$\frac{N_1}{f} = \frac{N_3}{f'} = \frac{(N_2 - N_1)}{R_1} - \frac{(N_2 - N_3)}{R_2} + \frac{(N_2 - N_3)(N_2 - N_1)t}{N_2 R_1 R_2} \tag{2.38}$$

$$\text{bfl} = f' - \frac{f't(N_2 - N_1)}{N_2 R_1} \tag{2.39}$$

Note that if N_1 and N_3 are equal to 1.0 (i.e., the index of air), these expressions reduce to Eqs. 2.36 and 2.37.

2.8 The Thin Lens

If the thickness of a lens element is small enough so that its effect on the accuracy of the calculation may be neglected, the element is called a thin lens. The thin-lens concept is an extremely useful one for the purposes of quick preliminary calculations and analysis.

The focal length of a thin lens can be derived from Eq. 2.36 by setting the thickness equal to zero.

$$\frac{1}{f} = (N - 1)(c_1 - c_2) \tag{2.40}$$

$$\frac{1}{f} = (N - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \tag{2.40a}$$

Since the thickness is assumed to be zero, the principal points of a "thin lens" are coincident with the location of the lens. Thus, in computing object and image positions, the distances s and s' of Eqs. 2.4, 2.5, 2.7, etc., are measured from the lens itself. The term $(c_1 - c_2)$ is often called the total curvature, or simply the curvature of the element.

Example E

An object 10 mm high is to be imaged 50 mm high on a screen that is 120 mm distant. What are the radii of an equiconvex lens of index 1.5 which will produce an image of the proper size and location?

The first step in the calculation is the determination of the focal length of the lens. Since the image is a real one, the magnification will have a negative sign, and by Eq. 2.7a we have

$$m = \frac{h'}{h} = (-)\frac{50}{10} = \frac{s'}{s} \qquad \text{or} \qquad s' = -5s$$

For the object and image to be 120 mm apart,

$$120 = -s + s' = -s - 5s = -6s$$

$$s = -20 \text{ mm}$$

and

$$s' = -5s = +100 \text{ mm}$$

Substituting into Eq. 2.4 and solving for f, we get

$$\frac{1}{100} = \frac{1}{f} + \frac{1}{-20}$$

$$f = 16.67 \text{ mm}$$

Noting that for an equiconvex lens $R_1 = -R_2$, we use Eq. 2.40a to solve for the radii

$$\frac{1}{f} = +0.06 = (N - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = 0.5\frac{2}{R_1}$$

$$R_1 = \frac{1}{0.06} = 16.67 \text{ mm}$$

$$R_2 = -R_1 = -16.67 \text{ mm}$$

2.9 Mirror

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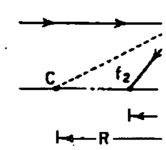

CONCAVE MIR
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Figure 2.13 The
surfaces.

Radius (R)		− 200		− 50	
Thickness (t)			− 80		
Index (N)	+ 1.0		− 1.0		+ 1.0
Ray height (y)		1.0		+ 0.2	
Ray slope × index (Nu)	0		− 0.01		− 0.002

Figure 2.15

The focal length of the system is given by $-y_1/u'_2 = -1.0/-0.002 =$ 500 mm. The final intercept distance (from R_2 to the focus) is equal to $-y_2/u'_2 = -0.2/-0.002 = 100$ mm, and the focal point lies 20 mm to the right of the primary mirror. Notice that the (second) principal plane is completely outside the system, 400 mm to the left of the secondary mirror.

2.10 Systems of Separated Components

It is often convenient to treat an optical system which is made up of separated elements or components (i.e., a group of elements treated as a unit) in terms of the component focal lengths and spacings instead of handling the system by means of surface-by-surface calculation. To this end we can introduce the paraxial ray height y into the equations of Section 2.3, just as we did in Section 2.6.

An optical component (which may be made up of a number of elements) is shown in Fig. 2.16 with its object a distance s from the first principal plane and its image a distance s' from the second principal plane. The principal planes are planes of unit magnification, in that the incident and emergent ray paths appear to strike (and emerge from) the same height on the first and second principal planes. Thus, in Fig. 2.16 a ray from the object point, which would (if extended)

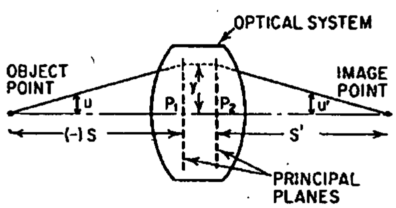

Figure 2.16 The principal planes are planes of unit magnification, so that a ray appears to leave the second principal plane at the same height (y) that it appears to strike the first principal plane.

strike the first principal plane at a distance y from the axis, emerges from the last surface of the system as if it were coming from the same height y on the second principal plane. For this reason we can write the following relationships:

$$u = \frac{-y}{s} \quad \text{and} \quad u' = \frac{-y}{s'}$$

and substitute $s = -y/u$ and $s' = -y/u'$ into Eq. 2.4:

$$\frac{1}{s'} = \frac{1}{s} + \frac{1}{f}$$

$$\frac{-u'}{y} = \frac{-u}{y} + \frac{1}{f}$$

$$u' = u - \frac{y}{f}$$

If we now replace the reciprocal focal length $(1/f)$ with the component power ϕ, we get the first equation of the set:

$$u' = u - y\phi \tag{2.41}$$

The transfer equations to the next component in the system are the same as those used in the paraxial surface-by-surface raytrace of Section 2.6:

$$y_2 = y_1 + du'_1 \tag{2.42}$$

$$u'_1 = u_2 \tag{2.43}$$

where y_1 and y_2 are the ray heights at the principal planes of components #1 and #2, u'_1 is the slope angle after passing through component #1, and d is the axial distance from the second principal plane of component #1 to the first principal plane of component #2.

These equations are equally applicable to systems composed of either thick or "thin" lenses. Obviously, when applied to thin lenses, d becomes the spacing between elements, since the element and its principal planes are coincident.

The preceding equations may be used to derive compact expressions for the effective focal length and back focal length of two separated components. Let us assume that we have two lenses of powers ϕ_a and ϕ_b separated by a distance d (if the lenses are thin; if they are thick, d is the separation of their principal points). The system is sketched in Fig. 2.17.

Beginning with a ray parallel to the axis which strikes lens a at y_a, we have

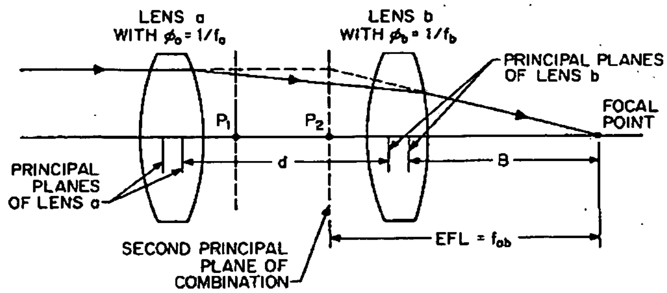

Figure 2.17 Raytrace through two separated components to determine the focal length and back focus distance of the combination.

$$u_a = 0$$

$$u'_a = 0 - y_a\phi_a \qquad \text{by Eq. 2.41}$$

$$y_b = y_a - dy_a\phi_a = y_a(1 - d\phi_a) \qquad \text{by Eq. 2.42}$$

$$u'_b = -y_a\phi_a - y_a(1 - d\phi_a)\phi_b \qquad \text{by Eq. 2.41}$$

$$= -y_a(\phi_a + \phi_b - d\phi_a\phi_b)$$

The power (reciprocal focal length) of the system is given by

$$\phi_{ab} = \frac{1}{f_{ab}} = \frac{-u'_b}{y_a} = \phi_a + \phi_b - d\phi_a\phi_b = \frac{1}{f_a} + \frac{1}{f_b} - \frac{d}{f_af_b} \qquad (2.44)$$

and thus

$$f_{ab} = \frac{f_af_b}{f_a + f_b - d} \qquad (2.45)$$

The back focus distance (from the second principal point of b) is given by

$$B = \frac{-y_b}{u'_b} = \frac{y_a(1 - d\phi_a)}{y_a(\phi_a + \phi_b - d\phi_a\phi_b)}$$

$$= \frac{(1 - d/f_a)}{1/f_a + 1/f_b - d/f_af_b} = \frac{f_b(f_a - d)}{f_a + f_b - d} \qquad (2.46)$$

By substituting f_{ab}/f_a from Eq. 2.45, we get

$$B = \frac{f_{ab}(f_a - d)}{f_a} \qquad (2.46a)$$

The front focus distance (ffd) for the system is found by reversing the raytrace (i.e., trace from right to left) or more simply by substituting f_b for f_a to get

$$(-)\text{ffd} = \frac{f_{ab}(f_b - d)}{f_b} \tag{2.46b}$$

Frequently it is useful to be able to solve for the focal lengths of the components when the focal length, back focus distance, and spacing are given for the system. Manipulation of Eqs. 2.45 and 2.46a will yield

$$f_a = \frac{df_{ab}}{f_{ab} - B} \tag{2.47}$$

$$f_b = \frac{-dB}{f_{ab} - B - d} \tag{2.48}$$

General Equations for Two-Component Systems

Using the same technique, we can derive expressions which give us the solution to all two-component optical problems. There are two types of problems which occur. With reference to Fig. 2.18, the first type occurs when we are given the required system magnification, the positions of the two components, and the object-to-image distance (neglecting the spaces between the principal planes of the components.) Thus, knowing s, s', d, and the magnification m, we wish to determine the powers (or focal lengths) of the two components, which are given by

$$\phi_A = \frac{(ms - md - s')}{msd} \tag{2.49}$$

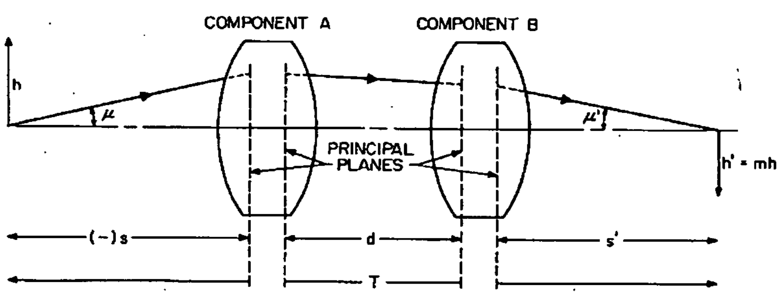

Figure 2.18 A two-component system operating at finite conjugates.